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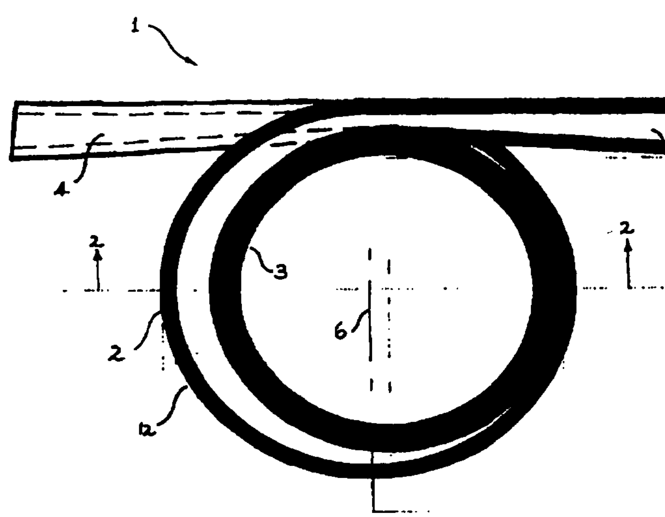
(54) Title: ORBITAL PERISTALTIC PUMP WITH DYNAMIC PUMP TUBE



(57) Abstract

A peristaltic pump (1) has a flexible tube (2) extending around an inner oscillatory ring (3) and confined by an outer stationary ring. Drive means, e.g. a radial array of hydraulic or piezo-electric actuators, effects the movement of the inner ring (3) to induce peristaltic compression along the tube (2). Reinforcements in the radially-inner and outer portions of the tube wall confine distortion, extension, etc. of the tube to the radially-intermediate portions such that compression of the tube in one region positively induces a corresponding expansion in a diametrically opposite region of the tube and enhances suction at the inlet of the pump. In a relaxed state the tube has an elliptical profile so that compression of the tube induces expansion of the tube to a circular profile in the suction region of the pump.

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"ORBITAL PERISTALTIC PUMP WITH DYNAMIC PUMP TUBE"

FIELD OF THE INVENTION

The present invention relates generally to pumps, and more particularly to peristaltic type pumps.

BACKGROUND OF THE INVENTION

Peristaltic pumps are well known, and typically comprise compression elements such as pressure rollers which are passed in succession along the length of the flexible tube to induce fluid flow through the tube by peristaltic compression. In the past, however, such pumps have generally been unable to generate sufficient pressure or flow rate to be effective in many commercial applications. They also require frequent maintenance, making them problematic even on a small scale, such as in medical applications.

One cause of these problems is that if the flexible tube is formed from a material sufficiently strong to withstand high internal pressures, then the tube also tends to be resistant to the required external compression from the pressure rollers. This leads to a requirement for relatively high energy inputs which in turn causes rapid mechanical wear. On the other hand, when softer and more flexible tubes are used, these have a lower pressure capacity. Even more significantly, because the tubes by nature need to be flexible, they have a tendency to collapse on the suction side, particularly after prolonged use. This characteristic substantially diminishes the performance, efficiency and reliability of the pump.

For these reasons, peristaltic pumps have hitherto been generally confined to low pressure and low flow rate applications such as in the medical field. Even in this area,

however, peristaltic pumps have typically been unable to provide the required characteristics in terms of performance, efficiency, reliability, consistency and longevity for use in numerous specialised applications, such as artificial hearts.

It is an object of the present invention to provide an improved pump which overcomes or substantially ameliorates at least some of these disadvantages of the prior art.

DISCLOSURE OF THE INVENTION

Accordingly, the invention as presently contemplated provides a pump comprising a flexible conduit extending around an inner compression element, a fluid inlet and a fluid outlet disposed at opposite ends of the conduit, and drive means selectively operable to effect relative rotary oscillation of the inner compression element thereby progressively to induce peristaltic compression along the conduit in a compression plane substantially normal to the axis of rotary oscillation whereby fluid is displaced from the inlet to the outlet of the pump, said pump further including peripheral support means operative to resist longitudinal extension of the conduit in the compression plane, such that compression of the conduit in one region by the inner compression element positively induces a corresponding expansion in a diametrically opposite region of the conduit, thereby enhancing suction pressure at the inlet of the pump.

Preferably, the inner compression element comprises a cylindrical compression ring around which the conduit is looped in a generally circular configuration. The peripheral support means preferably comprise a flexible substantially inelastic reinforcing element formed integrally with the outer radial side wall of the conduit.

In the preferred embodiment, a series of tensile reinforcing fibres preferably extend along the outer side wall of the conduit adjacent the compression plane to prevent localised

extension. Additionally, the peripheral support means preferably include at least one compressive reinforcing element extending along the inner side wall of the conduit to prevent localised longitudinal compression. Supplementary oblique or cross-ply reinforcing fibres may also be provided for more precise longitudinal shape control around the full circumference of the conduit.

Additionally or alternatively, the peripheral support means may comprise an outer support ring. In this embodiment, the conduit is preferably disposed between the oscillating inner compression ring and the outer support ring, which is fixed with respect thereto. In the preferred embodiment, the radial inner and outer side walls of the conduit remain substantially in constant contact respectively with the inner compression ring and the outer support ring.

In one embodiment, the drive means include a central drive pinion and a revolving planetary gear engageable with the drive pinion. The planetary gear is preferably disposed radially intermediate the drive pinion and the inner compression ring to effect localised compression of the adjacent section of the conduit. In this way, rotation of the drive pinion causes the planetary gear to revolve around the central axis of the pinion, which in turn effects the rotary oscillation of the inner compression ring to induce peristaltic compression along the length of the conduit.

In the preferred embodiment, the drive pinion, the planetary gear, and the surrounding inner compression ring are formed with complementary intermeshing gear teeth to facilitate the mechanical transmission of drive. In alternative embodiments, however, the drive surfaces may be essentially smooth, and formed from an elastomeric friction material such as neoprene or rubber.

In an alternative embodiment, the drive means may include a radial array of hydraulic or pneumatic linear actuators, the sequential extension of which induces the desired rotary oscillation of the surrounding inner compression ring. In an further alternative embodiment, a radial array of piezo-electric compression elements may be disposed around a fixed central hub and sequentially extended by the application of electric current from a controller. As a further alternative, the drive means may comprise an eccentric cam assembly.

In the preferred embodiment, the conduit has a circular transverse cross sectional profile in the fully expanded configuration. It is also preferred, however, that the tube is produced with an elliptical profile in the relaxed condition as manufactured, to minimise the extent of deformation from the relaxed condition during the cyclic compression and expansion phases. An elliptical shape advantageously divides the operational flexure into two opposite phases of bending, in effect halving the maximum extent of deformation from the intermediate relaxed position.

BRIEF DESCRIPTION OF THE DRAWINGS

Preferred embodiments of the invention will now be described, by way of example only, with reference to the accompanying drawings in which:-

Figure 1 is cross-sectional plan view showing a peristaltic pump according to the invention;

Figure 2 is a cross-sectional view of the pump taken along line 2-2 of Figure 1;

Figure 3 is a cross-sectional view similar to Figure 2, showing the variation in cross-sectional profile of the flexible conduit of the pump during the cyclic expansion and contraction phases;

Figure 4 is an enlarged cross-sectional view of the flexible conduit from the pump of Figures 1 to 3;

Figure 5 is a side elevation of the conduit showing the orientation of the primary and supplementary reinforcing elements in more detail;

Figure 6 is a perspective view of the conduit, removed from the pump;

Figure 7 is a cross-sectional view of the pump shown in Figure 1, incorporating a first form of drive means comprising a planetary gear train, according to the invention;

Figure 8 shows a second form of drive means, including an eccentric cam;

Figure 9 shows a third form of drive means incorporating a radial array of hydraulic actuators;

Figure 10 shows a fourth form of drive means comprising a radial array of piezo-electric compression elements;

Figure 11 is a transverse sectional view showing the elliptical cross-sectional profile of the conduit, in a relaxed configuration as manufactured;

Figure 12 is a transverse section showing the conduit of Figure 11 in the compressed configuration; and

Figure 13 is a transverse section showing the conduit of Figure 11 in the expanded configuration.

PREFERRED EMBODIMENTS OF THE INVENTION

Referring firstly to Figures 1 to 3, wherein like features are denoted by corresponding reference numerals, the invention provides a peristaltic type pump 1 comprising a flexible conduit or tube 2 extending around an inner compression ring 3. The conduit defines an inlet 4 and an outlet 5 for the pump. An internal drive mechanism is selectively operable to

effect rotary oscillation of the inner support ring 3 about a central axis 6, as discussed in more detail below. The rotary oscillation of the inner compression ring 3 about the central axis 6 induces peristaltic compression along the conduit in a compression plane 8 which is substantially normal to the axis of rotary oscillation 6. In this way, fluid is displaced from the inlet 4 to the outlet 5 of the pump.

As best seen in Figures 2 and 3, the conduit is disposed in an annular clearance space defined between the inner compression ring 3 and a fixed outer support ring 9, configured such that the inner and outer side walls 11 and 12 of the conduit remain substantially in constant contact respectively with the inner compression ring and the outer support ring. The outer support ring may be integral with or defined by an outer casing for the pump.

As best seen in Figures 4 and 5, the conduit includes a series of flexible substantially inelastic tensile reinforcing fibres 13 which extend longitudinally within the outer side wall 12 to prevent longitudinal extension of the conduit in the compression plane 8. Similarly, the conduit includes a series of flexible substantially inelastic compressive reinforcing elements 14 which run longitudinally along the inner side wall 11 to prevent longitudinal compression (and extension) of the conduit in the compression plane 8. It will thus be appreciated that the bulk of the peristaltic compression of the conduit is accommodated by deformation of the intermediate sections of the side wall. This arrangement of longitudinal reinforcing fibres in conjunction with the inner compression ring and the support ring operates such that peristaltic compression of the conduit in one region by the inner ring positively induces a corresponding expansion in a diametrically opposite region of the conduit. This prevents the conduit from collapsing and enhances suction pressure at the inlet of the pump. Supplementary oblique or cross ply reinforcing fibres 15 provide longitudinal shape control around the full circumference of the conduit.

As best seen in Figure 4, the primary and supplementary reinforcing elements are sandwiched between surrounding layers 16 of rubber or other suitable elastomeric material and additional reinforcement. The conduit further includes an inner lining 17 including longitudinally extending ribs 18 which enable the tube more readily to accommodate the required resilient deformation and subsequent restoration during each compression cycle.

Figure 7 shows a first form of drive means 20 comprising a drive pinion 21 in engagement with a revolving planetary gear 22. The planetary gear 22 is thus disposed radially intermediate the central drive pinion and the surrounding inner compression ring 3. The diameters of the respective gears are configured to effect localised radial compression of the conduit against the inner periphery of the outer support ring 9. It should be appreciated, however, that the outer support ring is optional due to the longitudinal reinforcing fibres 13 extending along the outer side wall of the conduit. Rotation of the drive pinion 21 causes the planetary gear 22 to rotate about its axis and simultaneously to revolve around the locus 22'. The resultant oscillatory displacement of the surrounding inner compression ring 3, progressively induces peristaltic compression along the length of the conduit in a clockwise direction, when viewing the drawings.

The drive pinion, planetary gear and the inner surface of the compression ring are formed in one embodiment with complementary intermeshing gear teeth to facilitate the mechanical transmission of drive from a suitable motor and gearbox assembly (not shown). In an alternative embodiment, however, the gear teeth may be replaced by substantially smooth drive surfaces, formed for example from an elastomeric material such as rubber, in which case the drive transmission is essentially frictional. In this case, the materials may be selected so as to allow slippage if a predetermined threshold pressure and hence torque are exceeded, thereby preventing the pump from being inadvertently overloaded.

Figure 8 shows a variation on the embodiment of Figure 7, wherein the planetary gear 22 is replaced by an eccentric cam 25 fixedly mounted on a central drive shaft 26. In this case, ball or roller bearings 27 are disposed between the outer surface of the cam lobe 25, and the cylindrical inner surface of the annular compression ring 3. It will be appreciated that this arrangement induces the same rotary oscillation of the compression ring as in the previous embodiment.

Figure 9 shows a further alternative embodiment wherein the drive means take the form of a radial array of hydraulic or pneumatic cylinders or actuators 30, operated via a pump and centralised controller (not shown). In this embodiment, the rotary oscillation of the inner compression ring is induced by sequential extension of the actuators in a clockwise manner, and the simultaneous retraction of the respective diametrically opposed actuators, as shown. The thrust from the actuators is reacted at the central fixed hub 31. At least three actuators are preferred. However, there is no upper limit, subject to size constraints and the level of control and smoothness of operation desired for the particular application for which the pump is designed. It should also be appreciated that the actuators need not be double acting since the unidirectional expansion of any selected actuator will automatically cause a corresponding compression or retraction in the diametrically opposing actuator, given the constant internal diameter of the surrounding compression ring 3.

In a particularly preferred embodiment, the maximum extent of travel, as well as the maximum threshold pressure, are pre-set to prevent over pressurisation of the system. In this way, the maximum extent of orbital off-set may be predetermined to facilitate the pumping of live specimens such as fish, without risk of damage. The same principle can be applied on a smaller scale to prevent damage to blood cells in medical applications.

Figure 10 shows a further variation in drive means, wherein the hydraulic or pneumatic actuators of Figure 9 are replaced by a radial array of piezo-electric compression elements 35. In this embodiment, instead of an hydraulic or pneumatic pump, a control voltage is applied sequentially to the compression elements by a centralised microprocessor controller (not shown) whereupon the compression elements sequentially expand to induce the desired rotary oscillation of the compression ring. This form of the invention is especially suitable for use on a miniature scale, for example in medical applications, wherein the minimum number of moving parts, relatively low power requirements and small size may be used to particular advantage.

As best seen in Figures 2, 3 and 4, the conduit has a generally circular cross-sectional profile in the fully expanded configuration. It is preferred, however, that the tube is formed with an elliptical profile in the relaxed condition as manufactured so as to reduce the extent of displacement and deformation during each compression phase. In terms of the pumping cycle, the conduit is shown fully compressed in Figure 12 and fully expanded in Figure 13. The elliptical profile of the conduit in the relaxed condition as shown in Figure 11 corresponds to the configuration of the conduit midway through a compression phase. It will thus be appreciated that the elliptical shape effectively divides the operational flexure into two opposite (i.e. tensile and compressive) phases of bending, rather than a single phase of twice the magnitude as would occur in a conventional conduit of circular cross-sectional profile when relaxed. This in effect halves the maximum extent of deformation from the relaxed or equilibrium condition.

More particularly, the conduit is formed on an elliptical mandrel having a minor axis X and a major axis Y as shown in Figure 11. If the internal diameter of the conduit in the

fully expanded circular condition is D, (see Figure 13) then the following relationships apply:-

$$X = \frac{D}{2}\text{; and}$$

$$Y = X \times 7^{0.5}$$

The significance of these mathematical relationships is that the inner circumference of the conduit (when viewed in transverse cross-section) does not substantially change, despite variations in the cross-sectional profile during the compression and expansion cycles. This in turn minimises internal stress and fatigue.

Advantageously, the pump according to the present invention is applicable to a wide variety of fluids and slurries with abrasive, corrosive or generally contaminate characteristics. It also has the capacity to be set up to generate a reasonable flow rate with only minimal compression. It is therefore able to accommodate relatively large particle size and may even be used to transfer live specimens, such as fish, between storage tanks. The invention is also well adapted for use in medical applications due to the minimal number of moving parts, the high efficiency, low power consumption, and the possibility of miniaturisation. More particularly, the invention provides a simple, inexpensive, and effective mechanism for ensuring full expansion of the peristaltic conduit which has the effect of enhancing the suction pressure and hence the overall efficiency of the pump. It also enables the performance parameters of the pump to be calibrated to within closer tolerances. Furthermore, because it is prevented from collapsing, the service life of the conduit is substantially increased, thereby enhancing reliability and reducing maintenance costs. Accordingly, in many respects the invention represents a commercially significant improvement over the prior art.

Although the invention has been described with reference to specific examples, it will be appreciated by those skilled in the art that the invention may be embodied in many other forms. For example, instead of inducing rotary oscillation of the inner compression ring within the surrounding conduit, the same effect could be achieved by oscillating the conduit or the outer support ring and fixing the inner ring with respect thereto, the relative displacement being the significant factor. Moreover, the inner compression element need not comprise a ring, but could include a series of discrete elements cooperating to perform effectively the same rotary oscillation function.

CLAIMS:-

1. A pump comprising a flexible conduit extending around an inner compression element, a fluid inlet and a fluid outlet disposed at opposite ends of the conduit, and drive means selectively operable to effect relative rotary oscillation of the inner compression element thereby progressively to induce peristaltic compression along the conduit in a compression plane substantially normal to the axis of rotary oscillation whereby fluid is displaced from the inlet to the outlet of the pump, said pump further including peripheral support means operative to resist longitudinal extension of the conduit in the compression plane, such that compression of the conduit in one region by the inner compression element positively induces a corresponding expansion in a diametrically opposite region of the conduit, thereby enhancing suction pressure at the inlet of the pump.

2. A pump according to claim 1, wherein the inner compression element comprises a cylindrical compression ring and wherein the conduit is disposed in a circular configuration around an outer periphery thereof.

3. A pump according to claim 1 or claim 2, and wherein the peripheral support means comprise a flexible substantially inelastic tensile reinforcing element effectively integral with an outer side wall of the conduit to prevent localised extension thereof in response to rotary oscillation of the compression element.

4. A pump according to claim 3, wherein the peripheral support means include a plurality of tensile reinforcing fibres extending along the outer side wall of the tube adjacent the compression plane.

5. A pump according to claim 4, wherein the peripheral support means include a compressive reinforcing element extending along the inner side wall of the conduit

adjacent the inner compression ring to prevent localised compression of the inner side wall of the conduit.

6. A pump according to any one of the preceding claims, wherein the conduit includes supplementary oblique or cross-ply reinforcing fibres for overall shape control.

7. A pump according to any one of the preceding claims, wherein the peripheral support means comprise a fixed outer support element or ring surrounding the conduit.

8. An pump according to claim 7, wherein the conduit is disposed between the inner compression ring and the outer support ring.

9. A pump according to claim 8, wherein the inner and outer side walls of the conduit remain substantially in constant contact respectively with the inner compression ring and the outer support ring.

10. A pump according to any one of the preceding claims, wherein the drive means include a central drive pinion and a revolving planetary gear engageable with the drive pinion, the planetary gear being disposed radially intermediate the drive pinion and the inner compression ring and configured to effect localised compression of an adjacent portion of the conduit, whereby rotation of the drive pinion causes the planetary gear to revolve around the pinion, thereby to effect rotary oscillation of the inner compression ring.

11. A pump according to claim 10, wherein the drive pinion, the planetary gear and the inner compression ring are formed with complementary intermeshing gear teeth to facilitate mechanical transmission of drive.

12. A pump according to claim 10, wherein the drive surfaces of the drive pinion, the planetary gear and the surrounding inner compression ring are essentially smooth, and formed from an elastomeric material to facilitate frictional transmission of drive.

13. A pump according to any one of claims 1 to 9, wherein the drive means include a plurality of hydraulic or pneumatic linear actuators, disposed in a radial array around a fixed central hub and extending outwardly to engage the inner periphery of the inner compression ring, whereby sequential extension of the actuators induces relative rotary oscillation of the compression element.

14. A pump according to any one of claims 1 to 9, wherein the drive means comprise a plurality of piezo-electric compression elements, disposed in a radial array around a fixed central hub and extending outwardly to engage the inner periphery of the inner compression ring, whereby sequential extension of the compression elements induces relative rotary oscillation of the inner compression element.

15. A pump according to any one of claims 1 to 9, wherein the drive means include an eccentric cam rotatable about a central axis to effect relative rotary oscillation of the inner compression element.

16. A pump according to any one of the preceding claims, wherein the conduit is initially formed with an elliptical internal cross sectional profile in a relaxed condition as manufactured, to reduce the extent of maximum deformation during each compression and expansion cycle.

17. A pump according to claim 16, wherein the elliptical profile of the conduit is defined by a minor axis X and a major axis Y, determined by the relationships:-

$$X = \frac{D}{2}; \text{ and}$$

$$Y = X \times 7^{0.5}$$

where D is the nominal internal diameter of the conduit when fully expanded to a circular cross sectional profile.

18. A pump according to claim 16 or claim 17, wherein the elliptical profile of the conduit is determined such that the internal circumference in transverse cross section does not substantially alter despite variations in cross-sectional profile during the peristaltic compression cycles.

19. A pump substantially as hereinbefore described, with reference to the accompanying drawings.

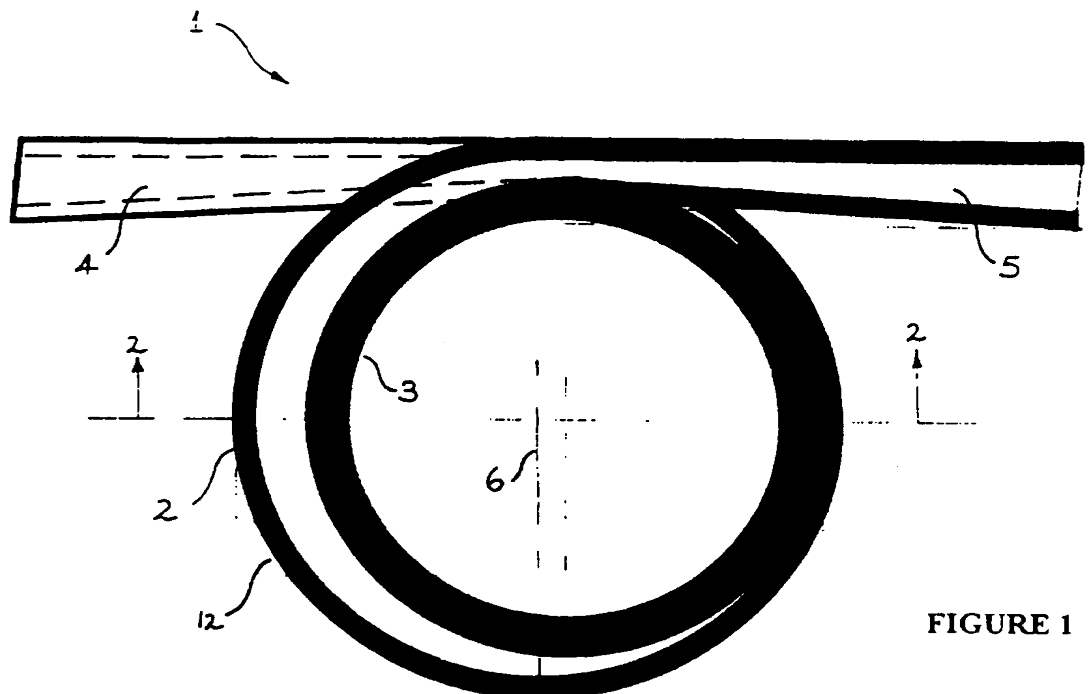

FIGURE 1

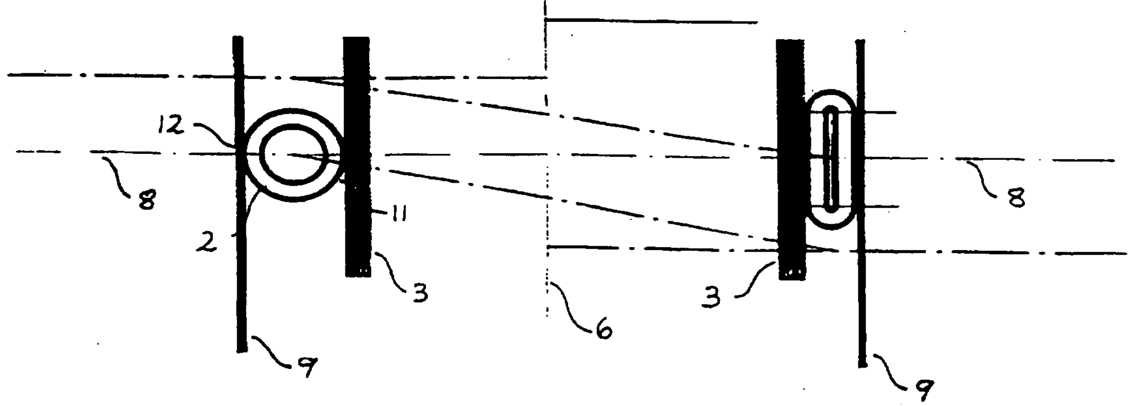

FIGURE 2

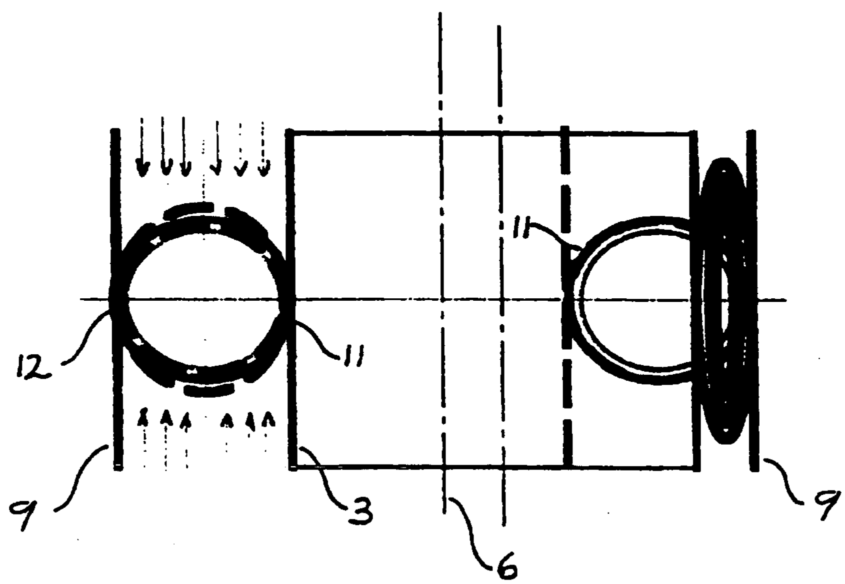

FIGURE 3

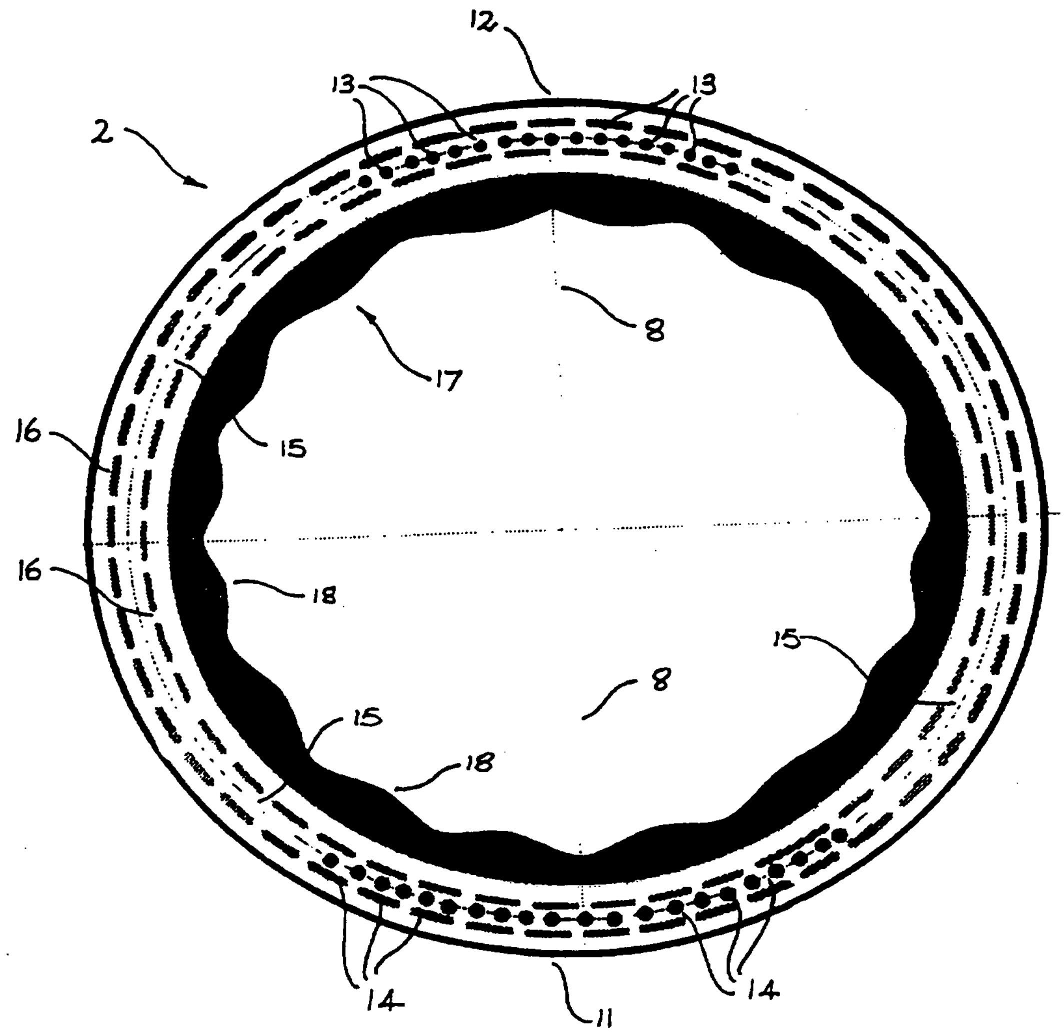

FIGURE 4

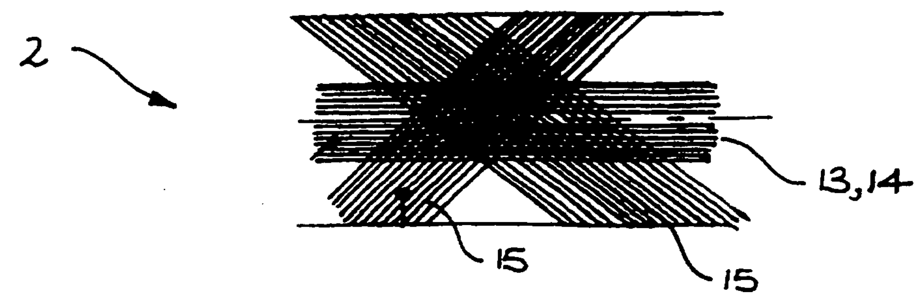

FIGURE 5

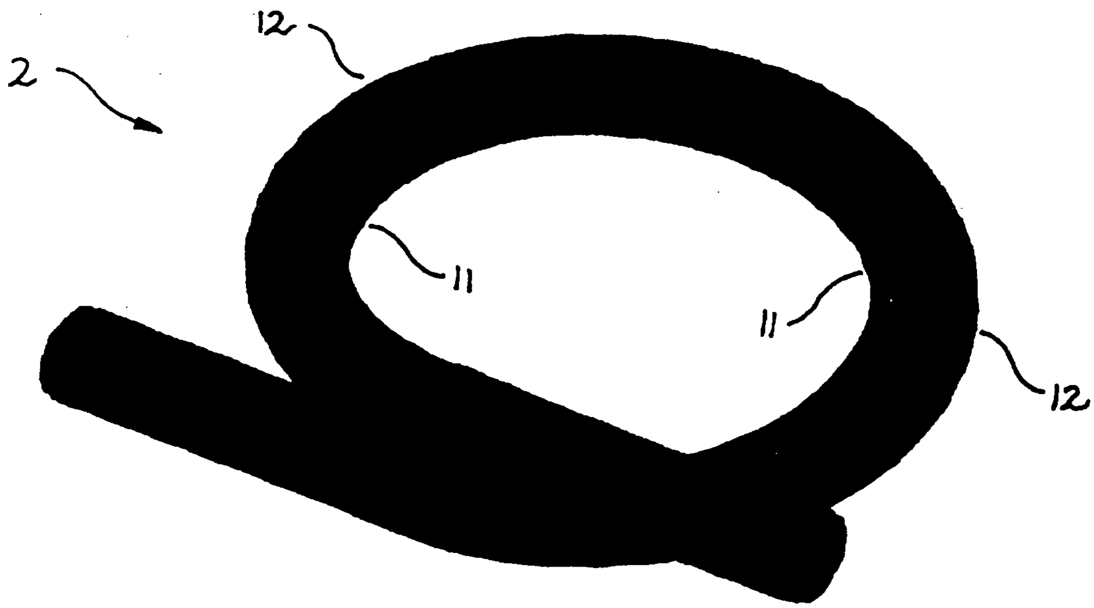

FIGURE 6

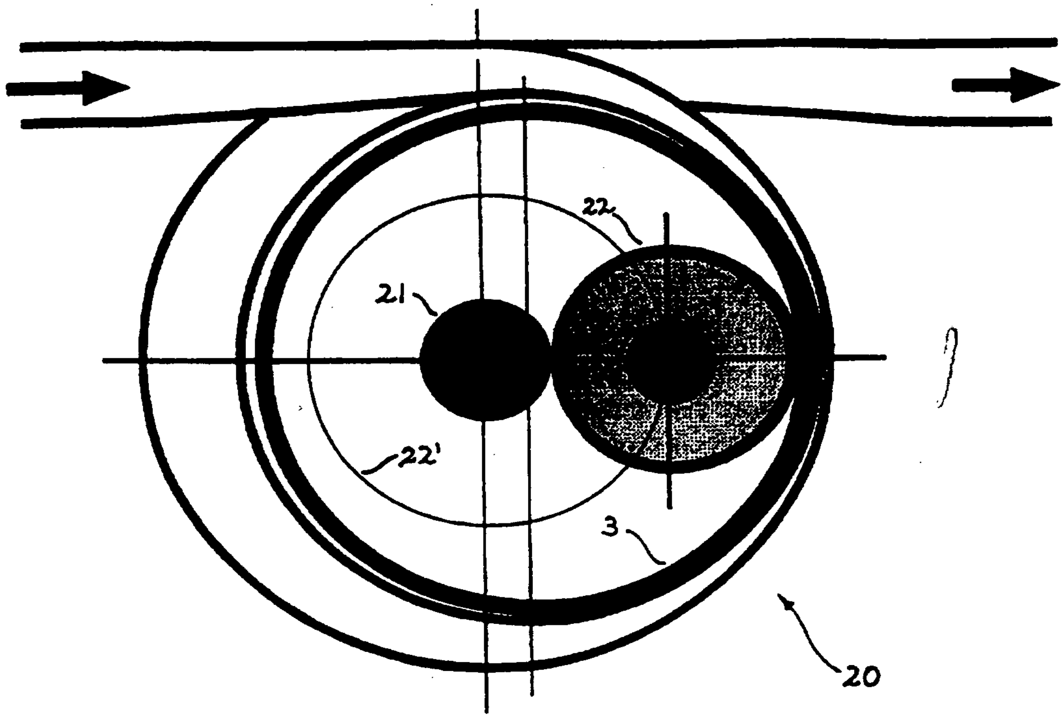

FIGURE 7

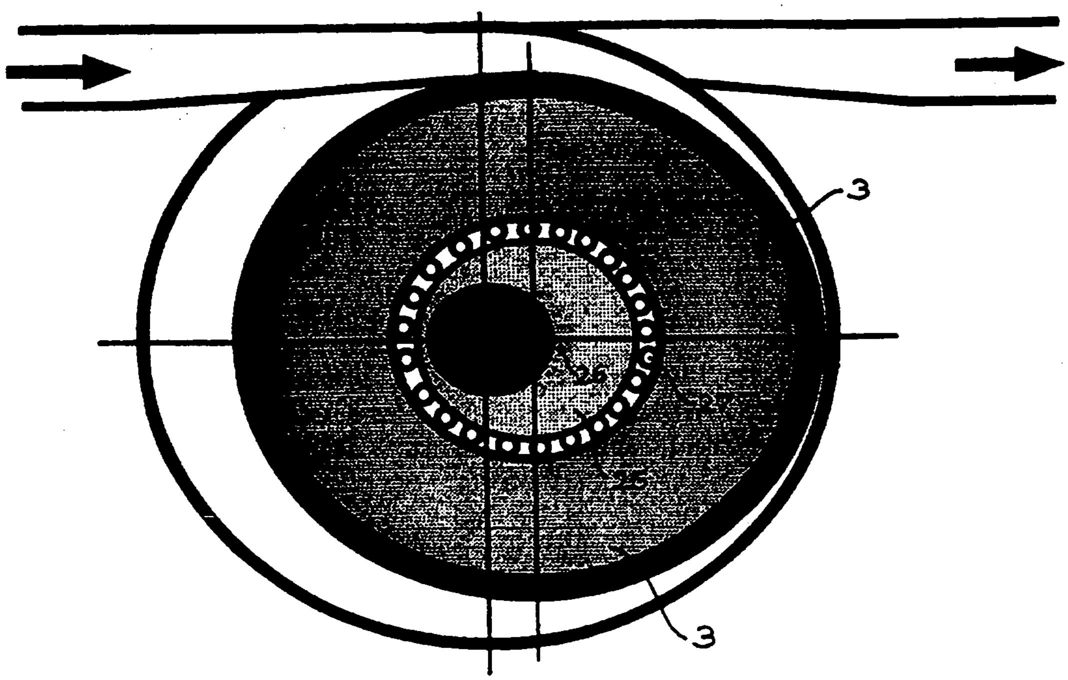

FIGURE 8

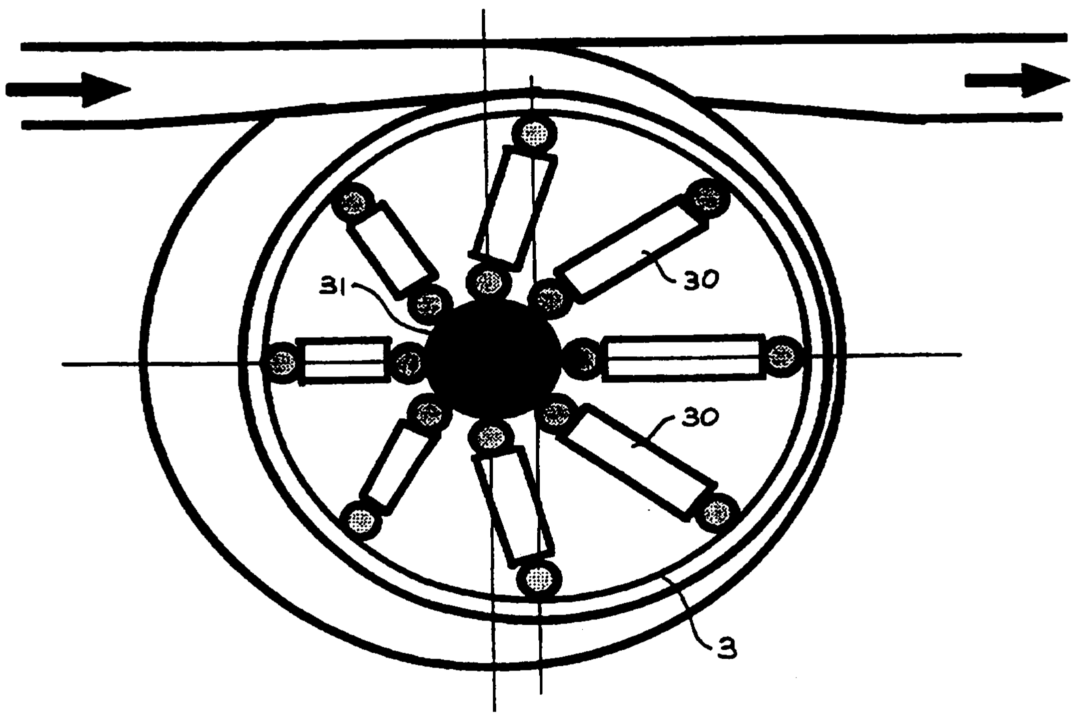

FIGURE 9

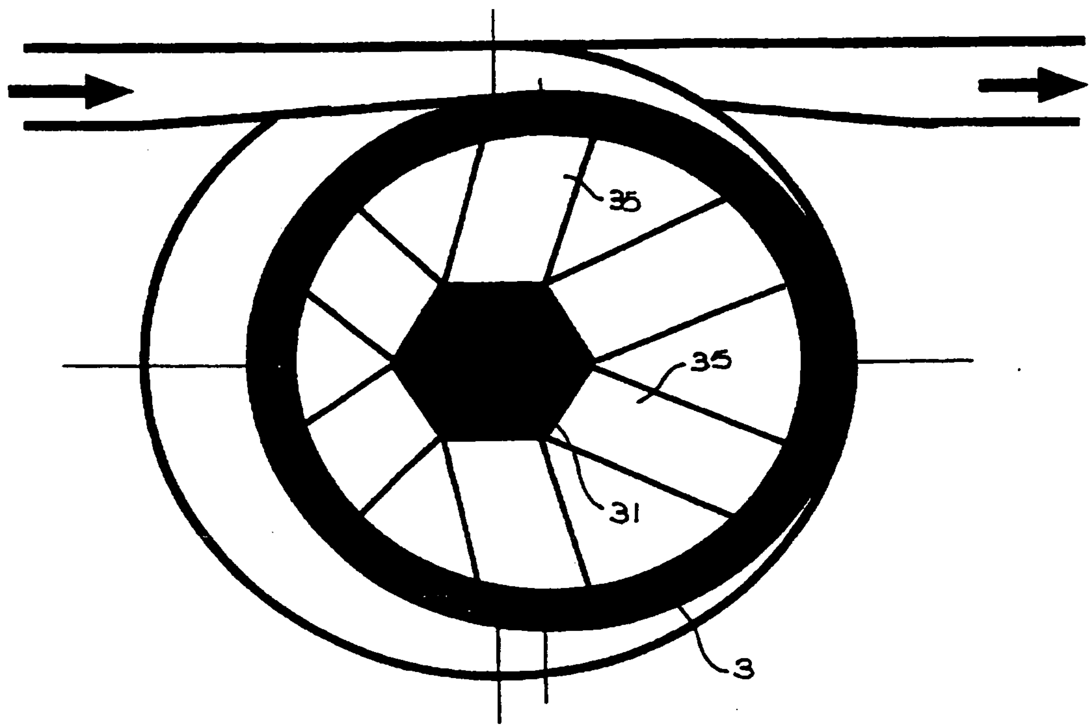

FIGURE 10

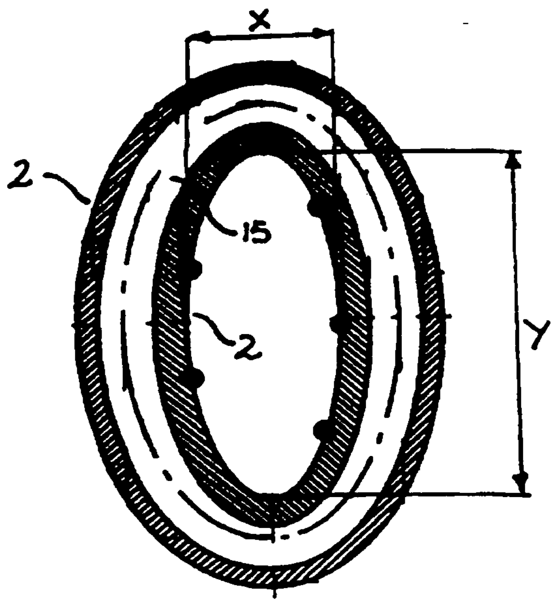

FIGURE 11

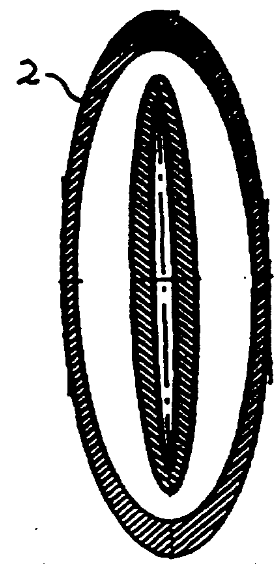

FIGURE 12

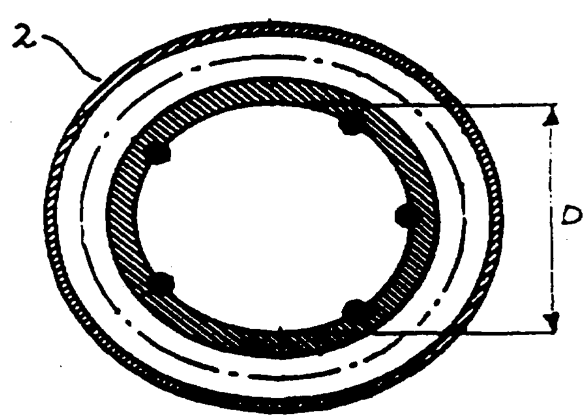

FIGURE 13

INTERNATIONAL SEARCH REPORT

International Application No.
PCT/AU 97/00242

A. CLASSIFICATION OF SUBJECT MATTER
Int Cl[6]: F04B 43/12
According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED
Minimum documentation searched (classification system followed by classification symbols) F04B 43/12, 45/08
Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched AU: IPC as above
Electronic data base consulted during the international search (name of data base and, where practicable, search terms used) DERWENT: IPC as above AND (REINFORCE: OR STRENGTH: OR TENSI: OR STRETCH: OR COMPRESS:)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 3 176 622 A (PFEIFFER) 6 April 1965 see whole document, but in particular lines 25-31, column 2 & lines 43-45, column 3	1-9, 15
A	US 3 887 306 A (GERRITSEN) 3 June 1975	
A	US 3 565 554 A (MULLER) 23 February 1971	

[X] Further documents are listed in the continuation of Box C

[ ] See patent family annex

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Date of the actual completion of the international search	Date of mailing of the international search report
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Name and mailing address of the ISA/AU AUSTRALIAN INDUSTRIAL PROPERTY ORGANISATION PO BOX 200 WODEN ACT 2606 AUSTRALIA Facsimile No.: (06) 285 3929	Authorized officer IAN KILBEY Telephone No.: (06) 283 2115

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C (Continuation)	DOCUMENTS CONSIDERED TO BE RELEVANT	
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	Derwent Abstract Accession N° G5115/25, class P64, Q56, NL 7316563 (POMPE W A M) 6 June 1975	
A	Derwent Abstract Accession N° A1905J/47, class Q56, SU 896 253 (SYNTH RESIN PLASTIC) 7 January 1982	